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* Application of the method of boundary variations to the calculation of electromagnetic scattering from the ocean.
* Introduction of new, high frequency approximations (series expansions in powers of the wavelength) for use in conjunction with boundary variations in ocean applications.
* Application of the method of boundary variations in the solution of eigenvalue problems.
* Development of fast high-order integral methods for solution of problems of electromagnetic scattering involving surfaces and volumes in three dimensional space.

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Submitted via email Jan 4, 2002

Dear Arje,

Below please find the final report for my AFOSR award #F49620-99-1-0010.

Would you please acknowledge your receipt?

Best regards,

Oscar Bruno

Electromagnetic Scattering

Grant #F49620-99-1-0010

Final Report

Oscar P. Bruno

January 2002

OBJECTIVES

* Application of the method of boundary variations to the calculation of electromagnetic scattering from the ocean

* Introduction of new, high frequency approximations (series expansions in powers of the wavelength) for use in conjunction with boundary variations in oceanic applications

* Application of the method of boundary variations in the solution of eigenvalue problems

* Development of fast high-order integral methods for solution of problems of electromagnetic scattering involving surfaces and volumes in three dimensional space

RECENT ADDITIONS TO THE RESEARCH PROGRAM

* Development of a perturbative technique for the normal mode problems associated with lasing cavities (extension of work on eigenvalue problems).

* Development of a perturbative technique for the numerical solution of the non-linear Schoedinger equation for the propagation of pulses in optical fibers.

* Solution of inverse problems related with Optical Coherence Tomography (Initial stages, in collaboration with graduate student Julian Chaubell. This work is being supported in part by a grant from the TRW foundation.)

INDUSTRIAL CONTACTS

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REPORT

BOUNDARY VARIATIONS/HIGH FREQUENCY APPROXIMATION FOR ROUGH SURFACE SCATTERING: MULTI-SCALE SOLVER

Our approach to the solution of rough-surface problems containing multiple scales (including oceanic scattering) is based on a combination of the ``Method of variation of boundaries'', developed earlier in collaboration with F. Reitich, and a high-order high-frequency approximation, developed recently in collaboration with A. Sei. Our last year's efforts allowed us to fully develop and demonstrate the capabilities of the combined high-order high-frequency solver with the boundary perturbation approach. The complete multi-scale algorithm, including boundary variations and high-frequency solutions, has been implemented in a Fortran code. Applications to various configurations of interest are currently underway.

Additional work in the area of perturbative methods concerns normal-modes in cavities. This work, in collaboration with undergraduate student Arnaud Durand, generalizes the perturbative method for eigenvalue problems of Bruno and Reitich to the physically relevant normal modes, that is, eigenvalue problems in all of space. (Mr. Durand spent the summer of 2001 visiting our group from Cachan, Paris.)

FAST INTEGRAL EQUATION SOLVERS: VOLUMETRIC SCATTERERS

The postdoctoral student McKay Hyde is working under my direction in the development of fast, high order solvers for problems of volumetric scattering. We currently have a fully tested version of our 2d code, as well as a three dimensional volumetric solver for smooth scatterers. This three dimensional solver has been implemented so as to run in a massively parallel environment. Current work in collaboration with F. Reitich, which is nearing completion, will provide the elements necessary to extend this solver to discontinuous scatterers. These solvers will be tested against experimental results given in the thesis of Jeffery M. Parks, Captain USAF - kindly provided to us by Andy Greenwood from AFRL.

FAST INTEGRAL EQUATION SOLVERS: SURFACE SCATTERERS

Over the last year L. Kunyansky and I a class of *high-order methods for singular surfaces*, that is, an algorithm which exhibits high order convergence even for surfaces containing corners, edges, etc. We have demonstrated high-order convergence in the well known ogive

geometry of EMCC: indeed, we have computed scattering from a 20*lambda ogive with several digits of accuracy in a three-hour computation on a 400 Mhz PC (with 1Gb of memory). To the best of our knowledge such accuracies are absolutely unprecedented for a singular geometry of this type, of a size as large as the one we considered; it is specially encouraging to find the required computation time was very small. A somewhat particular code was produced for singular surfaces, which showed that our strategies for edge problems are sound. Our present work seeks to produce a general code which can automatically incorporate CAD data, and can resolve geometric singularities without human intervention. This research is being conducted in contact with Lockheed Martin and the Jet Propulsion Laboratory. These solvers will be tested against experimental results which will be provided to us by Andy Greenwood from AFRL, as well as experimental data on models for the Mars lander provided by Vaughn Cable, from JPL. In a final related effort, we are developing, in collaboration with undergraduate student Stephane Lintner, integral equations suitable for the treatment of thin plates (such as a disc). These integral equations should play an important role in the treatment of air-vehicles. (Mr. Lintner spent the summer of 2001 visiting our group from Cachan, Paris, and he plans to join our group as a graduate student in 2002.)

OPTICAL COHERENCE TOMOGRAPHY

Optical coherence tomography is a non-invasive imaging technique based on the use of light sources exhibiting a low degree of coherence. Low coherence interferometric microscopes have been successful in producing internal images of thin pieces of biological tissue; typically samples of the order of 1mm in depth have been imaged, with a resolution of the order of 10 to 20 microns in some portions of the sample. Such images have been produced through renderings of the intensities of certain interference fringes as functions of the position of the light-focus within the sample; quite generally, limited post-processing of this data has been used. In our work, in collaboration with graduate student J. Chaubell (under partial support of TRW) we address, in a mathematically rigorous manner, the inverse (Maxwell) problem of producing the actual values of the refractive index within the sample from given low-coherence interferometric data. Once obtained, such a map of the refractive index variations is useful in a variety of ways; in particular, a straightforward display of this map yields an image of the internal structure of the sample. Our work over the last year has produced, for the first time, a well posed inverse solver based on optical coherence. We expect important developments may follow from these contributions.

PERTURBATIVE SOLUTION OF THE NON-LINEAR SCHOEDINGER EQUATION FOR MODELLING OF OPTICAL FIBERS

In collaboration with former postdoctoral associate D. Amundsen (now assistant professor at Carleton's mathematics department (Canada)) we developed a perturbative technique for the solution of the fully nonlinear Schroedinger equation. This work, which was motivated by contacts with Corning (NY) and Fiberspace (CA) has produced a highly efficient solver - which can speed up computations by as much as one hundred times. This is a significant accomplishment, since some industrial applications require repetitive solution of these

equations, each one of which requires of the order of 10 hours. This technique should be useful in other nonliner evolution problems, and, we believe, it generally has a very significant potential indeed. The basis of the method is to utilize analytic continuation *instead* of finite differences in the numerical method. Thus, much longer time steps can be used in an algorithm which is essentially explicit, and at the same time unconditionally stable.

ADDITIONAL EFFORTS

In addition to these efforts related to electromagnetic scattering, in the last year this PI was involved in a variety of research efforts in the general area of materials science, including work on graphite-to-diamond phase transitions induced by shock waves (in collaboration with postdoctoral associate Dimitri Vaynblat, and, most recently, with Prof. Ruben Rosales (MIT) and his student John Wheatherwax), work on magnetoelastomers (in collaboration with Prof. Liliana Borcea, Appl. Math., Rice University); and solution of free boundary problems arising from finance (in collaboration with graduate student Andy Greenberg).

ARCHIVAL PUBLICATIONS

Low-coherence interferometric imaging: Solution of the inverse scattering problem, O. Bruno and J. Chaubell, in preparation.

Analytic time-stepping: a high-order perturbative approach to non-linear fiber optics, D. Amundsen and O. Bruno, in preparation.

A fast high-order method for scattering by inhomogeneous media in two-dimensions: theoretical considerations, O. Bruno and M. Hyde, in preparation.

A fast algorithm for the simulation of polycrystalline misfits II: martensitic transformations in three space dimensions, G. Goldsztein and O. Bruno, Submitted to J. Mech. Phys. Solids.

A fast high-order solver for problems of scattering by heterogeneous bodies, O. Bruno and A. Sei, submitted to IEEE Trans. Antenn. Propag.

A Fast, High-Order Algorithm for the Solution of Surface Scattering Problems II: Theoretical Considerations, L. Kunyansky and O. Bruno, Submitted to J. Comp. Phys.

High order high frequency solutions of rough surface scattering problem, O. Bruno, A. Sei and M. Caponi, To appear in Radio Science.

On the magneto-elastic properties of elastomer-ferromagnet composites, L. Borcea and O. Bruno, To appear in J. Mech. Phys. Solids

Surface scattering in 3-D: an accelerated high-order solver, O. Bruno and L. Kunyansky, Proc. Roy. Soc. London A, 457, pp 2921-2934, 2001.

Shock-induced martensitic phase transitions: critical stresses, Riemann problems and applications, O. Bruno and D. Vaynblat, Proc. Roy. Soc. London A, 457, pp. 2871-2920, 2001

Two-wave structures in shock-induced martensitic phase transitions, O. Bruno and D. Vaynblat, Mathematical and Computer Modelling 34, pp. 1261-1271, 2001

A Fast, High-Order Algorithm for the Solution of Surface Scattering Problems: Basic Implementation, Tests and Applications, O. Bruno and L. Kunyansky, J. Comp. Phys. 169, pp. 80-110, 2001.

Boundary-variation solution of eigenvalue problems for elliptic operators, O. Bruno and F. Reitich, The Jour. Fourier Anal. Appl. 7, pp. 169-187, 2001.

A fast high-order solver for EM scattering from complex penetrable bodies: TE case, O. Bruno and A. Sei, IEEE Trans. Antenn. Propag. 48, pp. 1862-1864, Dec. 2000.

Numerical simulation of martensitic transformations in two- and three-dimensional polycrystals, O. Bruno and G. Goldsztein, J. Mech. Phys. Solids 48, 1175--1201, 2000.